MODELLING PERFORMANCE PARAMETERS OF ROUNDABOUTS USING GAP ACCEPTANCE METHOD FOR INDIAN TRAFFIC SCENARIO

Master of Technology

In

Transportation Engineering

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ODISHA – 769 008

MAY 2015

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

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CERTIFICATE

This is to certify that the thesis entitled, "MODELLING PERFORMANCE PARAMETERS OF ROUNDABOUTS USING GAP ACCEPTANCE METHOD FOR INDIAN SCENARIO" is a record of bonafide work and sincere efforts carried out by **Yadu Krishna** under my supervision and is submitted in partial fulfillment of the requirement for the award of **Master of Technology in Civil Engineering** with specialization in **Transportation Engineering** in the Department of Civil Engineering**,** National Institute of Technology, Rourkela, Odisha for the academic year 2013-2015. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Date**:**

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ACKNOWLEDGEMENT

First of all, I offer my sincere gratitude and respect to my project supervisor, Dr. P.K. Bhuyan, Professor of the Civil Engineering Department, for his invaluable support and suggestions throughout the course of my study. I consider myself extremely fortunate to have had the opportunity of associating myself with him for one year. This thesis was made possible by his patience and persistence attitude.

I am very thankful to Dr. S.K. Sahu, HOD of Civil Engineering Department, Dr. Mahabir Panda and Dr. U.C. Chattraj for their helpful suggestions during my entire course work. I also extend my sincere thanks to the Department of Civil Engineering.

I express my sincere thanks to the different officials and friends from different parts of the country who have helped a great deal to collect the vast data sets and Ashish Patnaik, Research Scholar NIT Rourkela for his support and suggestions.

I also want to convey sincere thanks to my family and friends especially Shweta, Priyanka and Haritha whose timely support and belief in my abilities have helped me complete this course . I would also like to present my gratitude to my friends and colleagues at the Transportation Engineering specialization for making my stay in the campus a pleasant one.

Yadu Krishna

ABSTRACT

Road network connecting the various parts of the country defines the economy of the nation. This lead to vast development of road infrastructure. Intersections form a major unit of the road network. It is of utmost importance to design these intersections safely as they are the areas where maximum conflict points exist, which could otherwise lead to fatal. One such implication can be introducing roundabouts at intersections, which reduces the conflict points, thus providing greater safety and efficient traffic flow. The drivers' behavior is one of the prime factors which influence the performance of these roundabouts. No such procedure of analysis is available in Indian context to identify the performance of roundabouts. To develop such a model, initially, the parameter defining driver behavior, i.e. Gap acceptance parameters had been estimated for heterogeneity in traffic. For this purpose, data was collected from 10 sites from different regions of India, giving priority to variations in traffic and driver behavior. The critical headway was then determined using three methods, namely, Raff, Ning Wu and Maximum Likelihood, for determining the appropriate one for the model. These parameters were then utilized in deriving an equation for entry capacity in Indian context. The equation obtained satisfied the sites with high circulating flow. When compared with other existing gap acceptance models, the German model mostly over predicted the capacity as compared to developed model, while the HCM model underestimated the same.

Keywords: Roundabouts, gap acceptance, capacity, heterogeneity

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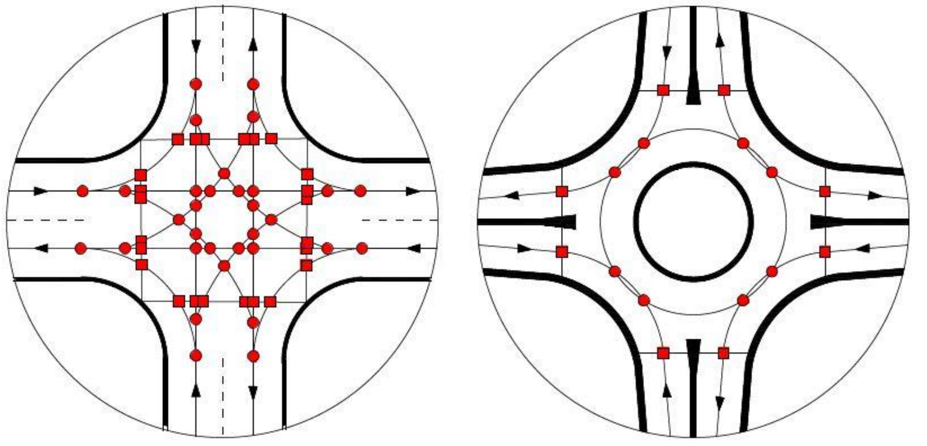
ABBREVATIONS, SYMBOLS and UNITS

ARCADY	Assessment Of Roundabout Capacity And Delay
ARRB	Australian Road Research Board
AWSC	All way stop controlled
FHWA	Federal Highway Administration
h	hour
HCM	Highway Capacity Manual
IRC	Indian Road Congress
LMV	Light Motor Vehicle
MLM	Maximum Likelihood Method
NAASRA	National Association of Australian State Road Authorities
NCHRP	National Cooperative Highway Research Program
PCU	Passenger Car Units
RODEL	Roundabout Delay
sec	seconds
SIDRA	Signalized Intersection Design and Research Aid
t_c	Critical Gap
t_f	Follow-up Time
TRRL	Transport Road Research Laboratory

1. INTRODUCTION

1.1. General

Roundabout is a type of unsignalised intersection were the minor traffic from different lanes merges with the major traffic circulating around the central island. The central island is usually circular in shape. Streamlining of the traffic flow at entry is obtained by channelization so as to reduce the severity and number of conflict point at the intersection. Channelization is done by thorough geometric design which enables tangential merging of traffic with the circulating flow at desirable speed.



COMPARISON OF NUMBER OF CONFLICT POINTS		
INTERSECTION	ROUNDABOUT	NORMAL 4-WAY
VEHICLE - VEHICLE ●	8	32
VEHICLE - PEDESTRIAN ■	8	24

Fig 1.1 Conflict point comparison

Road is that place for a human were all his senses need to work at a perfect rhythm to get him from his origin to the destination in one piece. When it comes to intersection were two or more road meet and the vehicles in these roads compete for a common physical space, the whole scene gets a bit mushy. Intersection is that component of a road network were maximum number of accidents have been reported. A comparison of a normal four way intersection and roundabout as shown in Fig 1.1 gives the basic idea of number of conflict point involved in different intersections. Roundabout as seen drastically reduces the number of conflicts and eliminates the need to stop at the yield point.

Other than improving safety by reducing the number of conflict point and free merging of minor traffic into major traffic there are many more advantages of using roundabouts as an intersection alternative like,

- Traffic calming at intersection without the use of signals.
- Facilitate U-turn.
- Lower overall delay when working within the capacity limits thus benefiting to the environment in terms of noise reduction, less fuel consumption etc.
- Pedestrian safety, as it provides relaxation points at medians. And
- Less maintenance cost than signalised intersection.

So to avail all these advantages from a roundabout one has to design it considering the various requirements of the traffic, people and the location.

A Brief History from Time

Various studies on roundabouts has taken place in many major developed countries from the start of this century. The earliest noted use of something similar to a roundabout is around 1791 by Major L'Enfant in the Washington street road network. Unsignalised intersection took couple of centuries to evolve from the human powered traffic control to the modern roundabout as shown in Fig 1.2.

Various theories too evolved over time to explain the performances of these intersections. During the 1930's rotaries came into use, where the minor traffic merged with the major flow tangentially and at considerable speed. These were unlike the earlier traffic circles were the traffic intersected the circle perpendicularly. Weaving theory were used to explain its performance. This theory failed due to the increasing size of the rotaries and high speeding traffic at the weaving part. Thus the roundabouts were born using the yield-at entry rule and it thrived. Failure of weaving theories called for new theories to explain the performance. Using the work done by J.C Tanner British researchers developed a new theory named the Gap acceptance theory. Research then developed independently in many nations and as a result many models were developed to satisfy their native traffic needs.

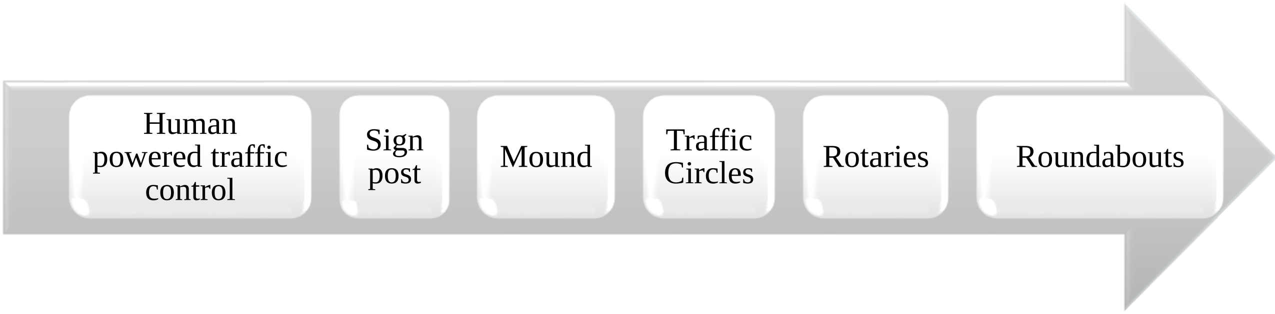


Fig 1.2. Evolution of unsignalised intersection from human powered to modern roundabout

1.2. Problem Statement

As these researches developed in different countries many capacity models were formed using the traffic characteristics, geometrics and/or behavioural pattern of the drivers towards the traffic. Nations like USA, UK, Australia, France, Germany, and Switzerland etc. developed their own model from the extensive data collected from various roundabouts from their native road networks. Later, they have showed promising improvement and have upgraded their model using updated data. Many computer software were also developed for better assessment like RODEL, ARCADY and SIDRA.

When this topic is taken to India for a comparative study one can see that there is not much work done over the subject. The code which is under use for design of roundabout in India is IRC: 65-(1976). Actually this 22 page code is not for the design of “roundabouts” but that for the design of “traffic rotaries” which is long forgotten in the timeline. This code is purely outdated though being a revised version of the original, published in 1955. It uses the weaving theory and the capacity of the weaving part is determined using some geometrics and proportion of the weaving traffic as it is assumed to accommodate the least traffic. This clearly shows that the code is purely incapable of representing the driver behaviour at roundabouts.

1.3. Objective and Scope

As stated earlier there is no existing codes or models to explain the performance of roundabouts for Indian roads. The traffic on the other hand is so heterogeneous that the composition won't ever match with those in any developed nations. The Indian roads are infamous for its rickshaws, encroached and heavily packed street ways and mainly for the off side and illegal driving throughout the world. The main aim of this study is to obtain an understanding between this heterogeneity in traffic composition and the general attitude of Indian drivers towards his fellow 'colleagues' at a roundabout. The expected result is an indigenous model to explain the performance of roundabout by utilising the driver gap acceptance behaviour at the entry of roundabout.

Extensive and legitimate data is required to develop a full on model. The main parameter which is used in the gap acceptance method is the critical gap. There are many existing methods to determine the same. Utilising these methods the value which is most suitable to explain the Indian driver gap acceptance behaviour can be obtained. Using the collected data a comparative study after calibration of the different existing gap acceptance models throws light on their suitability for Indian conditions.

1.4. Organisation of the report

The report is organised in such a way so to explain the flow of the study in the best possible manner.

Chapter 1 gives an introduction to the study. It gives a brief history of roundabouts and the changing trends in theories used to explain the performances. What the developed countries have achieved and what our country have yet to resolve has also been reminded. The issue which had to be addressed regarding roundabouts and the goal set to resolve that issue has been discussed.

Chapter 2 provides the detail review of many works done by researchers regarding various aspects of roundabout performance. The works done on gap acceptance theory, different methods to estimate gap parameters and various existing performance models to estimate capacity based on these parameters has been discussed. Distribution pattern of headways in a stream considered has also been explained in brief.

Chapter 3 is on methodology. It explains in detail the various methods adopted to obtain the gap acceptance parameters at different sites. The method used to develop a model to evaluate capacity based on these parameters has also been stated.

Chapter 4 addresses in detail the location and properties of various sites considered to collect data for the purpose of developing the model. Detailed explanation for why each site has been considered has also been elaborated. The detailed process of data collection and various parameters which has to be studied from the site has been explained.

Chapter 5 shows the various results obtained from the study conducted on the collected data. Comparative analysis of various methods used to obtain the gap acceptance parameters has been done. The validity of various existing gap acceptance models for Indian scenario has also be stated after its calibration.

Chapter 6 provides the summary and conclusion of the work done so far on determining the performance of roundabout using the developed model and the vital conclusions drawn from comparison study has also been explained. Further scope for this study is also noted here.

2. LITERATURE REVIEW

2.1 General

Capacity is defined as the maximum entering flow on each leg when one of the entry becomes saturated. It is a performance gauge and very important parameter for design. There are many models in existence like German by Tanner and Wu, Swiss by Bovy et al, UK by TRRL, Australian by Akçelik and HCM 2010 (USA). All these models developed till date to determine the capacity of a roundabout, are using one or the other of the three set of parameters given below:

i Roundabout configurations

ii Geometric details

iii User Behaviour and geometric aspects

HCM 2010, an improvised version of HCM 2000 is a manual regarding various aspects of highway design in USA. Chapter 21 of this manual is about detail study of roundabouts. It includes various design and analysis aspects of roundabouts like level of service, data inputs for the analysis and also the scope and limitation of the methodology. Regarding the calculation of capacity of the roundabout, two methods namely the regression analysis and the gap acceptance model had been considered. It also included various capacity concepts required for calibration of the models.

Based on the above method, a manual providing the detail description of developing and calibrating the model for changes in roundabout geometry was prepared NCHRP 572. It was improvised to NCHRP 672(2010) recently including the recent trends in roundabouts around the world. Various performance analysis parameters of the roundabout like, level of service, data inputs for the analysis and also the scope and limitation of the methodology were explained in detail. It explains in detail the gap acceptance theory to develop the model based on driver behaviour. In addition, a model based on regression analysis is also provided in brief. A web document on NCHRP 572 regarding the roundabouts states in detail the various literature available around the world on roundabout regarding its safety, performance and operation analysis.

2.2 Critical Gap and Follow-up Time

The work on estimation of critical gap using statistical techniques started quite a while ago. The initial work which came to lime light was done by Raff (1950) by taking the probabilities of accepting and rejecting a gap for a given time interval. The point of intersection of plots of accepted and rejected gap is taken as critical gap. After that a series of methods were developed using different statistical approaches, few of them are Ashworth method (1969), Seilogh's method (1973), Maximum likelihood method, Logit Method, Probit Method and equilibrium of probabilities method, etc. Maximum likelihood among these was used by many researchers using different distributions like log-normal or Erlang distribution. Since then many studies were conducted to check the efficiency and validity of the results obtained by these methods in many parts of world.

All the above stated methods were discussed in details along with few other methods like Hewitt's method, Harder's method, etc. by Brilon et.al for roundabout conditions in USA. Many factors influencing the flow in both the streams were considered. As a results, wide variation was found in value obtained from these methods, but the one obtained by maximum likelihood method and the Hewitt's method were found to be more accurate as they proved to satisfy two more sites.

Tian et.al (2000) further investigated on the field of critical gap to find out various factors affecting it, when a roundabout is considered. The geometry, vehicular delay, type of vehicle, traffic movement and the speed limits were identified as the influential factors. The difference was noticed based on number of lanes in the entry and a considerable variation was found between the value of gap for the passenger cars and the heavy vehicles.

Ashalatha and Chandra (2011) proposes an alternate procedure for estimating the critical gap at an unsignalised intersection making use of clearing behaviour of vehicles in conjunction with the gap acceptance data. Earlier studies on critical gap estimation are reported from homogeneous traffic conditions. As vehicular interactions and driver behaviour under mixed traffic condition is a bit complex in nature.

Among the new models developed to estimate critical gap was the one by Wu (2012), based on equilibrium of probabilities method. It discarded all the vague assumptions made in earlier models regarding homogeneous behavior of drivers and rejected gap to be always less than an accepted one. This proved to be a strength to the model to give prove appropriate results. The procedure to estimate the critical headway was also simple and could be estimated using few statistical analysis.

2.3 Gap Acceptance Models

2.3.1 Existing Models

Research and study on roads and its different components is something that started centuries ago. Through time, catering the growth and behaviour of traffic, intersections has evolved to the modern roundabouts. Many models have been developed using either the roundabout configurations or the geometric aspects as parameters. But the main variable which affects the capacity of a roundabout is the human behaviour. To better explain this variable gap acceptance theory was put to use. Early models include those of Tanner (1962), Ashworth and Laurence (1978) and Seigloch. All these models have been developed to suit the native traffic conditions in nations like USA, Germany and Australia. Some of the existing models are:-

HCM Model (United States of America)

The latest edition of Highway Capacity Manual (HCM 2010) gives a new model for determining entry capacity of single lane and multi-lane roundabouts. It is developed using the field measured parameter values on the early Seigloch model form. One of the main strength of this model is that it is developed using significant quantity of data collected from 31 roundabouts in USA.

German Model

German model underwent rapid evolution from the start of 20th century. Stuwe (1991), Brilon and Stuwe (1993), Brilon, Wu and Bondzio (1997), Brilon (1997) and Wu (2001) is the path by which the German model developed till date. Its model is basically based on gap acceptance method. New formulas are being developed combining conflict matrix model with gap acceptance by Wu

2.4 Other Major Researches

A gap acceptance model taking into account the proportion of exiting vehicles was developed by Hagring (2000). Here an assumption is made to explain the influence of the exiting vehicle on the gap acceptance process, that when they leave the roundabout new gaps that consists of combinations of old gaps arise. The entry capacity of a minor stream is strongly affected by the proportion of exiting vehicles which depends on the position of the exiting point.

The capacity of small roundabouts with two-lane entries in Switzerland was studied by Lindenmann (2006) on six roundabouts. It was found that even that though the space requirements were same in case of both single lane entry and dual lane entry roundabouts, the capacity in case of later was found to be higher and better in terms of performance with respect to capacity, traffic flow, and driver behaviour, as well as a high level of safety.

The misconception of SIDRA and UK TRL being the pure empirical model was proved wrong by Akcelik (2011) by comparing the results obtained from various other methods like HCM 2010, FHWA, German Linear Regression and Gap acceptance Model. It was proved that the SIDRA model is based on the gap acceptance criteria but still is an empirical method as it needs large amount of empirical data sets for generation of model.

2.5. Comparative Studies

Polus and Shmueli (2011) conducted an analysis and evaluated the entry capacities of around six small to medium sized roundabouts. Models for entry capacity into the rotary were developed and were compared with other existing models. This model depends on the geometry and the expected traffic conditions. Entry capacity depends particularly on the diameter of the outside circle of the intersection. The geometric characteristics determine the speed of vehicles around the central island.

2.6Summary

The detail study on the performance and capacity analysis of roundabouts done till date regarding various aspects involved in it proved that the driver behaviour of accepting and rejecting a gap is an important factor in deciding the entry capacity of a roundabout. Of the many methods used to determine these gap acceptance parameters like critical headway, the Raff method, Equilibrium of Probabilities method (Wu) and the Maximum likelihood method were found to give better results when validated. Regarding Indian condition, it was found that very scare work has been done on the capacity evaluation of roundabouts thus arising a need to develop model for heterogeneous traffic conditions in India.

3. STUDY METHODOLOGY

3.1. General

Two methods have been traditionally followed to estimate capacity of roundabouts, empirical (regression analysis) and stochastic (gap acceptance method). Nowadays micro simulations are also used to explain the phenomena. The basic way a roundabout works is by allowing the traffic from different lanes (entry flow) to enter and merge with the circulating traffic (conflicting flow) and make a clockwise maneuver around the central island then exit through the desired lane. Many models have been developed to explain this simple activity around a roundabout there by determine its various performance parameters.

In this study the behavior of drivers at the entry of a lane towards an oncoming gap in the circulating lane is taken into account. Whether to accept or reject the particular gap to enter into the conflicting flow is a major decision every driver has to make at this point. To explain this a probabilistic method namely the gap acceptance method is used. It is represented using parameters like critical gap and follow up time. The distribution of headways between priority vehicles in the conflicting flow and the usefulness of these to the entering vehicles are also taken into account.

For developing a model, initially gap parameters are to be estimated using the compiled data sets. Critical gap is a stochastically distributed value and is hard to obtain directly from the site measurements. There are many existing methods to determine the same. A comparative analysis of the different existing methods is done to determine the most suitable value for Indian conditions. Follow-up time is also determined from the videos collected. Relationship between these values along with the regression coefficients obtained from relating entry and circulating flow of each site is used to develop a model. Later a comparative study is carried out between the developed model and various existing calibrated models.

3.2. Entry and Circulating Flows

Traffic flow entering from different lanes are considered as the minor flow and traffic circulating around the central island is considered as the major or the conflicting flow. These flow values can be said as the foundation for model development and the values for every lane are required exclusive of its gap acceptance parameters. The flow data can be obtained by many methods like videography, directly from site or using new ITS gadgets.

Each are every flow, may it be minor or major is heterogenic in nature. Light motor vehicles, bicycles, two- wheelers, heavy vehicles and even animal drawn vehicles are seen on the Indian roads. Each of these are counted separately and converted into PCUs. The conversions for vehicles to PCU values were taken from IRC 65-1976. The PCU values for different types of vehicles is shown in table 3.1.

Table 3.1. PCU conversion factors based on IRC 65-1976

Sl.No	Vehicle Type	Conversion Factor
1	Two- wheelers (motor cycles)	0.75
2	Car and other four- wheelers	1
3	Heavy vehicles	2.8
4	Animal drawn vehicles	5
5	Bicycles	0.5

3.3. Estimation of Gap Acceptance Parameters

3.3.1. Estimation of critical gap (t_c)

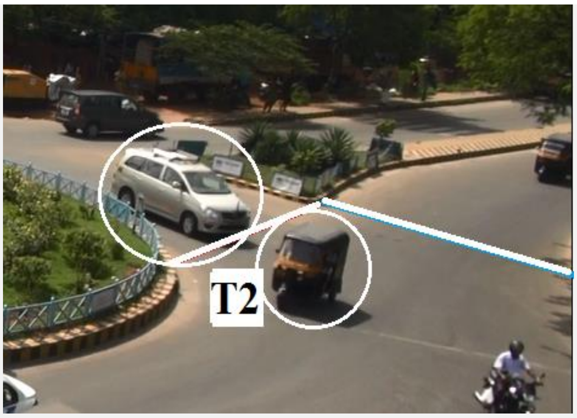
There are many methods available to estimate the critical gap such as Raff (1950), Ashworth (1970), Seilogh (1973), Troutbeck (1992), Equilibrium of probabilities by Ning Wu (2006), Logit and Probit method. Of these available methods Raff method, Maximum Likelihood and Equilibrium of probabilities method were used for estimating critical gap.

i. Conflict Lines L1 and L2 under consideration

ii. First follow-up time stamp Ft1

iii. Second follow-up time stamp Ft2

iv. First Critical gap time stamp T1



v. Second Critical gap time stamp T2

Fig 3.1. Images showing time stamp for data extraction

For the purpose of estimating the critical gap, gaps accepted and rejected by driver at the entry of roundabout are to be extracted from the video. To obtain these, two imaginary lines are to be considered, one at the entry of lane of roundabout (L1) and another at the line of conflict (L2) as shown in Figure 3.1 (i). To estimate a gap, two time stamps are considered. The time when front bumper of a vehicle in minor stream (entry flow) touches the imaginary line L1 is considered as the first time stamp $T_{1,}$ as shown in Figure 3.1 (iv). The time at which the front bumper of the vehicle in the major stream of the headway under consideration touches L2 is considered as the second time stamp $T_{2,}$ as shown in Figure 3.1 (v). The gap is then calculated, as the difference between theses time stamps T_2 and T_1 and for every gap calculated, it's checked whether the gap was accepted or rejected.

Different methods used for determination of critical gaps considered in this study is described in detail below.

- Raff method
- Equilibrium of Probabilities Method (Wu Method)
- Maximum likelihood method

3.3.2. Estimation of the Follow-up Time (t_f)

The follow-up time is the time gap between the two consecutive vehicles in an entering stream. This parameter is used to show the continuous flow of traffic accepting a single gap in the circulating flow. To calculate the follow-up time, an imaginary line L1 is considered along the entry of the lane as shown in Figure 3 (i). Two time stamps are used to note two activities to determine the follow-up time.

When continuous flow takes place utilizing a single gap the time at which the back bumper of the first vehicle crosses the line L1 is noted using the first time stamp Ft1 and the time at which the front bumper of the following vehicle touches the line is noted by Ft_2. The condition at which each time stamp is noted is clearly described in Fig 3.1. (ii) and 3.1. (iii). The follow up time is the difference between these two time stamps. The average value of all the readings is the follow-up time which is considered for further analysis.

3.4. Headway Distribution

The gap acceptance models are based on assumption that the headways in the major stream (conflicting flow) follow certain distribution. This distribution of headways and the usefulness of these headways can be said as the two basic elements of gap acceptance models. Relation between the critical gap and follow-up time gives the usefulness of these headways. The distribution is described using statistical functions like M1 (negative exponential), M2 (shifted negative exponential) and M3 (bunched exponential).

3.5 Development of Model

Before developing an equation to estimate the capacity of the roundabouts few prerequisites such as traffic flow data, gap acceptance parameters (critical gap and follow- up time) are essential as explained earlier. All these values are initially obtained from the data collected and compiled. The relation between entry and the circulating flow is established from minute by minute data of traffic flow at each entry of every roundabout. The relationship is considered as exponential for obtaining a better fit with the data.

After obtaining this relationship, a proper headway distribution is taken into account. As the traffic data at roundabout sites mostly comprised of saturated flow, continuous bunching of vehicles is observed. Thus, M1 pattern of headway distribution is considered for developing the model. The equation for capacity with gap acceptance parameters (t_c and t_f) and conflicting flow as independent variables is then generated using regression analysis for the available data set.

3.6. Existing models based on Gap Acceptance Theory

As stated earlier, vast work has been done in field of gap acceptance theory to use it as a tool to estimate the capacity of roundabouts in many developed nations. Some of these methods have been accepted globally for use in native traffic conditions with certain reforms or calibrations. Among these, one of the most accepted model is HCM 2010. Another model based on this theory is the German. A comparative study between these existing models are also conducted.

4. STUDY AREA AND DATA COLLECTION

4.1. General

While studying about the different existing models one thing that was seen in common is the extensive data set that was used to develop each of them. Entry flow, circulating flow, headways in the entry and circulating lane etc. are some of the major parameters which were used to develop these models. These parameters gives the basic description about the nature of traffic and behaviour of driver at the point of entry. When the whole process is regenerated in Indian scenario couple of other things need to be sorted out.

India is diverse in everything. When it comes to traffic, it is infamous for the heavily jammed metropolis, rash driving bikers, the rickshaws which pulls into every nook and corner humanly possible and the nature of drivers, which can get a bit aggressive at times. The selection of study area should be such that all the factors which causes the heterogeneity is taken into consideration. So while doing the reconnaissance certain basic factors need to be taken into consideration like,

- Characteristics of city.
- Location of the roundabout.
- Type of the roads the roundabout connect.
- Nearby places of socio-economic importance.

To develop a model the first requirement is an extensive and legitimate data set which defines various heterogenic parameters frame by frame. To satisfy the various requirements following cities with roundabouts were considered for the study.

4.2. Study Area

Initial search for roundabouts started by studying the road maps of major cities. Many were located but during the initial site visit many of them turned out to have been changed to ‘signalised roundabout’ intersections. This scenario was seen basically inside the city area, must be mainly to manage the heavily rising traffic flow.

4.2.1. Chacka Junction, Trivandrum, Kerala

Kerala, the state located at the extreme southernmost tip of the motherland has the Arabian Sea at one side and the state of Tamil Nadu on the other. Though small in area, it is one among the densely populated states in India. The coastal line runs about 580km in length and houses some of the major ports of India itself. Due to the presence of many natural and man-made harbours and abundant backwaters it has grown into a hub for trade and commerce. The road network here is well distributed to cater various needs of the people but the national highways are the narrowest when compared with those in other states.

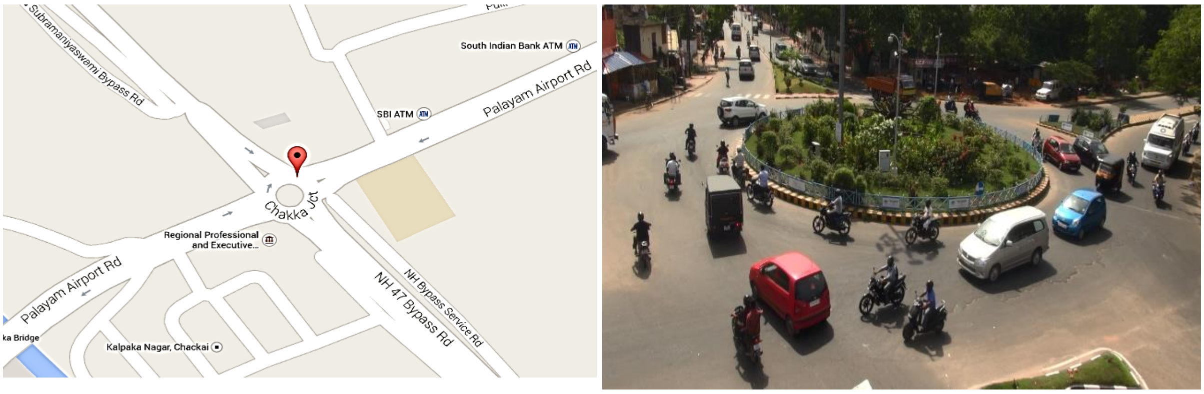


Fig 4.1. Roundabout at Chacka, Trivandrum

The city under study is Trivandrum, which is the capital of Kerala. It houses all major administrative and government offices along with many rising industries, IT parks and places of tourist interest. Chacka junction, a four lane roundabout is one of the busiest junctions in Trivandrum where the parallel bypass road of NH 47 joins with Palayam-airport road. NH 47 bypass road covers some of the major landmarks like Beemapally Mosque, Technopark, Kovalam beach etc. Palayam Airport Road is mainly used by the people going to the outskirts of the city. The traffic through these roads are always in a near saturated condition during peak hours due to the various offices and educational institute it connects. A site map of the junction showing the various roads it connects and a picture of the morning traffic it manages is shown in Fig 4.1.

4.2.2. Ramnagar Square, Nagpur, Maharashtra

Maharashtra as the name says is a very large state which lies at the western part of the nation. The Arabian Sea covering about 720km of coast line lies to its west and is surrounded by the states of Karnataka, Telangana, Goa, Gujarat, Chhattisgarh and Madhya Pradesh. As the latest census says it is the world's second most populous sub-national entity. It has the largest road network in India. Though having many major rivers in the state, the cargo coming through the many existing ports uses road networks for conveying as these are not navigable.

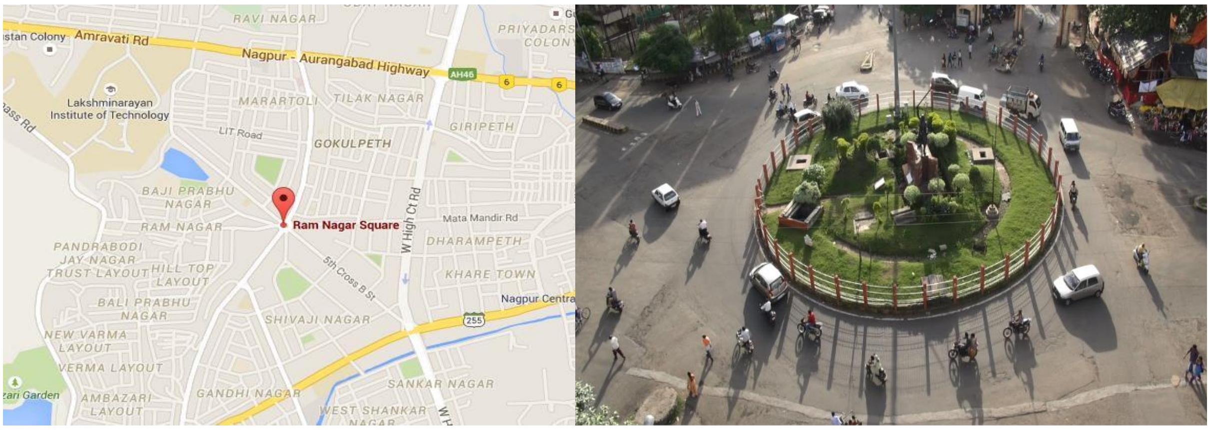


Fig 4.2. Roundabout at Ram Nagar, Nagpur

Nagpur is the third largest city of Maharashtra. It is considered as the cultural capital and is a major commercial and political centre. It has been endowed as 'The Best Indian city to live in' in terms of liveability, greenery and other indices. This city have some of the premium educational institutions making it a major education centre in central India.

The intersection under consideration is a seven lane roundabout, the Ram Nagar Square at Dharampeth. It looks like an epicentre of a web of roads which runs through many residential areas, educational institutes and various places of commercial activities between two major roads namely AH46 towards north and SH255 towards south. A detailed map and a picture of the site condition is shown in Fig 4.2. Presence of schools, colleges and residential colonies are observed in the vicinity. This can be a major factor to increase the rate of traffic during the peak hour. More number of two- wheelers and bicycles can be seen to be used by the people in this area.

4.2.3. Master Canteen, Bhubaneswar, Odisha

Odisha is naturally rich state located on the eastern side of the nation. It has a 485km long coastline on its eastern side along the Bay of Bengal and is surrounded by the states of West Bengal, Jharkhand, Chhattisgarh, Telangana and Andhra Pradesh. Naturally rich means it contains a fifth of India's coal and iron ore and a rich deposit of bauxite and chromite. Odisha is seen as a fertile field for investments by many indigenous and foreign companies. The rate of growth of this state in various fields is very astounding. The presence of three major ports is playing a major role in this development.

Bhubaneswar is the capital city of Odisha. It is one of the modern India's planned cities and a fast developing one. Tourism is a major industry here. Currently it is divided into two parts the old city and the new one. The old city mainly has many residential areas and couple of major temples. This area is congested and roads here are very narrow. Whereas the planned city which was designed to house the capital has all major government buildings, schools, shopping centres and dedicated residential area. Roads are designed in a grid pattern inside the city. Traffic mainly consists of two-wheelers and light motor vehicle. Rickshaws are also seen in many numbers inside the city.

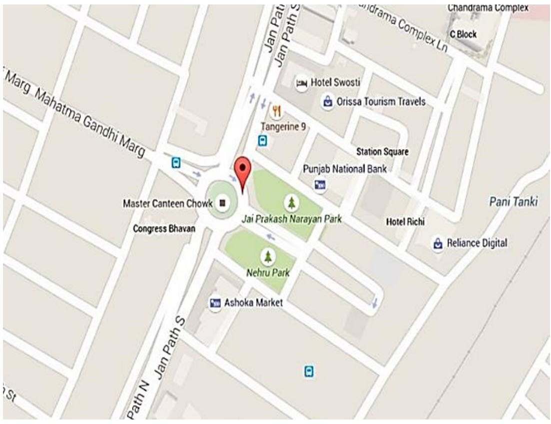


Fig 4.3. Roundabout at Master Canteen, Bhubaneswar

Roundabout from which the data was collected is the Master Canteen chowk near Bhubaneswar railway station. It is the junction where Mahathma Gandhi marg and Jan Path road which runs parallel to NH 203 intersects. Very heavy traffic is seen throughout the day as its location is at the heart of the city. Almost all government and administrative offices are in the vicinity of this roundabout, which includes the secretariat. Couple of schools colleges and hospital lies along these roads which makes the peak hour traffic heavier.

4.2.4. Panposh Chowk, Rourkela, Odisha

Rourkela is another major city in the state of Odisha located in the northern border side. It is the Steel city and industrial capital of Odisha. It has one of the largest steel plants, The RSP (Rourkela Steel Plant). The city is well connected by roads, rail and a private airstrip. It is located on the Howrah-Mumbai rail track which gives an added advantage for the transport of goods and raw materials. This city is divided into several townships namely the Steel, Civil and Fertilizer Township.

Panposh Chowk is a three lane roundabout located at the outskirts of the city on the banks of Brahmani River. It can be said as the gateway of the city. Two of the three lanes of this roundabout is NH 23 which goes through Ranchi and Rourkela connecting Chas in Jharkhand with Nuahata in Odisha, hence contributing to heavy traffic flow. The third road goes into the city centre, hence the traffic is very high during peak hours. The traffic comprises mostly of the people going for work and the heavy vehicles transporting raw materials and goods to and fro the steel plant. Large number of heavy vehicles can be found at this roundabout.

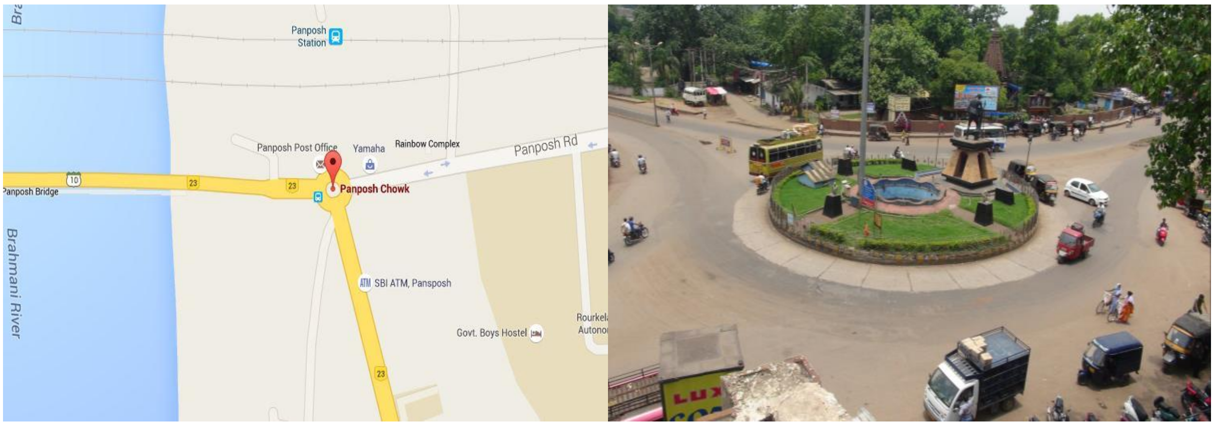


Fig 4.4. Roundabout at Panposh Chowk, Rourkela

4.2.5. Salt Lake, Kolkata, West Bengal

Fig 4.5. Roundabout at Salt Lake, Kolkata

West Bengal is one among the oldest states which have witnessed the growth and fall of many kingdoms and many activities which trimmed the face of modern India as we see it today. The geographical location of the state with Himalayas in the north and the Bay of Bengal in the south and the presence of Bhagirathi and Hooghly rivers has given it a strategic position in the logistic department of the nation.

Salt Lake City or Bidhannagar is basically a planned satellite town developed to accommodate the growing population of the city. It is a growing hub of economic and IT sectors. The intersection under study is basically a four lane roundabout near National Institute of Technical Teacher's Training & Research formed by the 1st Cross road and Fourth Avenue. The area is basically a residential area but lot of educational institutes, hospitals and commercial buildings are also present. SH 1 runs parallel to it which is also a good traffic provider to this intersection. Private vehicles of people living in these residential complexes along with the well-connected public transport systems and taxi and rickshaw services provides for the traffic of this roundabout.

4.3. Data Collection

Developing a model to determine the capacity and other parameters of a roundabout calls for an extensive and legitimate data set. This data set includes the traffic flow entering and circulating around various existing roundabouts and the geometric parameters involved with it. As the study mainly revolves around the driver gap acceptance behaviour, the geometrics is considered to have no role in it. To study the nature and to conduct the quantitative analysis of the flow conditions, video graphic recordings were taken during the suitable situation.

Reconnaissance of the above discussed sites gave an initial idea about the traffic condition of the city and the layout of the site. Time when various offices, schools and other educational institutions started and finished for a day gave an idea about the peak hour condition of traffic in the city. Presence of commercial and social activity regions were also considered. During this peak hour the roads transforms into a saturated mode and is the perfect time to take the videos. The hunt for a good position to keep the camera was the next hurdle. Mainly tall towers or high rise buildings were targeted. A good position is where we get,

- a view which is crystal clear, without much obstacles in the line of sight.
- all lanes and traffic flow in a single window in zoomed in position to ease up the extraction process.
- a safe cover for camera and other equipment from oncoming wind and rain.

The data was collected for two to three hours during the peak hour period. High definition cameras were used for collecting the data. These cameras gave a clear output even in full zoom mode, which helped in the extraction process later. Tripod with its horizontal and vertical angular adjustments enabled easy placement of camera to obtain a clear view of the site avoiding as much obstacles in the line of sight as possible.

5. RESULTS AND ANALYSIS

5.1. General

After collecting videos from the various sites as discussed in the earlier chapter, many data were extracted from it which included those which can be directly be obtained from the site and data which has to be processed for the values of different parameters which we need for developing the model. The data which are directly obtained from videos like the composition of traffic at every entry and circulating lanes of the roundabouts is tabulated in detail below. Traffic is categorised into bicycle, motorcycle, light motor vehicle, heavy vehicle and animal drawn vehicle to estimate the rate of heterogeneity we are dealing with and is recorded as PCU/hr.

Apart from the flow data, different headways and follow- up time were also extracted from the video. The headways extracted from the video were further statistically modelled to obtain the critical gaps. The follow-up time on other hand had been taken as the average value of all the readings. The traffic flow per hour for both entry and conflicting roadways at different junctions has been shown below. Later the details of the newly developed model has been shown along with results of the comparative study with other existing models.

5.2. Data extracted from videos

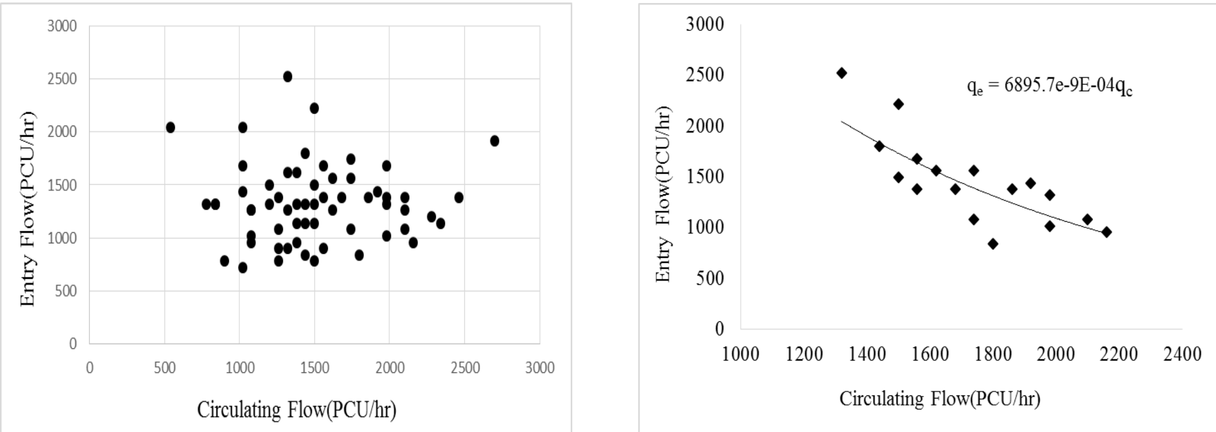
From the collected data, the entry and the circulating flow had been extracted for one minute intervals. The number of vehicles for this one minute were converted into PCU's and then further transformed into PCU/hr.

5.2.1. Chacka Junction, Trivandrum, Kerala.

Table 5.1. Details of traffic volume at Chacka Junction, Kerala

DETAILS OF ENTRY TRAFFIC VOLUME						
Leg Direction	Heavy Vehicle	Light Motor Vehicle	Motor Cycle	Bicycle	Total Vehicles	Traffic Volume (PCU/hr)
NE	63	928	830	32	1853	1743
NW	96	820	838	6	1762	1653
SE	91	785	808	11	1695	1651
SW	48	580	782	25	1435	1313
DETAILS OF CIRCULATING TRAFFIC VOLUME						
NE	79	554	541	9	1183	1185
NW	42	737	955	24	1758	1583
SE	58	675	676	18	1427	1353
SW	83	881	875	3	1842	1771

The scatterplot showing the relationship between the entry and the circulating flow along with regression best fit for the SW entry lane of Chacka Junction is shown in Fig 5.1.



(a) (b)

Fig 5.1. (a) Scatterplot for entry to circulating flow (b) relationship between entry and circulating flow for SW approach of Chacka Junction

5.3. Critical Gap and Follow-up Time

5.3.1 Critical gap using Raff method

The headways extracted from the site data sets, have been analysed to obtain critical gap using Raff method. The probabilities of rejecting and accepting a certain gap was found out for every headway. Then, cumulative probabilities were computed and graph was drawn between the cumulative probabilities of accepting and rejecting a gap. The point of intersection of two plots is taken as critical gap. The table showing sample of details of Raff method for Chacka Junction is given below.

The plot showing the graph obtained by cumulative probabilities to obtain critical gap is shown in Fig 5.2. The critical gap for the Chacka Junction, using Raff method can be estimated as 1.96 sec.

Table 5.2. Brief details of computing critical gap using Raff method

Time Interval (sec)	Time Interval (sec)*10	Accepted /Rejected	IF C=R, NR=N+1	IF C=A, NA=N+1	Fr= E/Nrmax	Accepted Probability	Rejected Probability
0.28	0.357143	R	3	1	0.013575	0.004902	0.986425
0.32	0.3125	R	4	1	0.0181	0.004902	0.9819
0.52	0.192308	R	11	3	0.049774	0.014706	0.950226
0.56	0.178571	A	11	4	0.049774	0.019608	0.950226
0.68	0.147059	R	24	5	0.108597	0.02451	0.891403
0.72	0.138889	A	24	6	0.108597	0.029412	0.891403
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
1.04	0.096154	R	61	17	0.276018	0.083333	0.723982
1.08	0.092593	A	61	18	0.276018	0.088235	0.723982
1.48	0.067568	R	101	46	0.457014	0.22549	0.542986
1.52	0.065789	A	101	47	0.457014	0.230392	0.542986
1.76	0.056818	R	119	64	0.538462	0.313725	0.461538
1.8	0.055556	A	119	65	0.538462	0.318627	0.461538
.	.	.	.	.	.	.	.

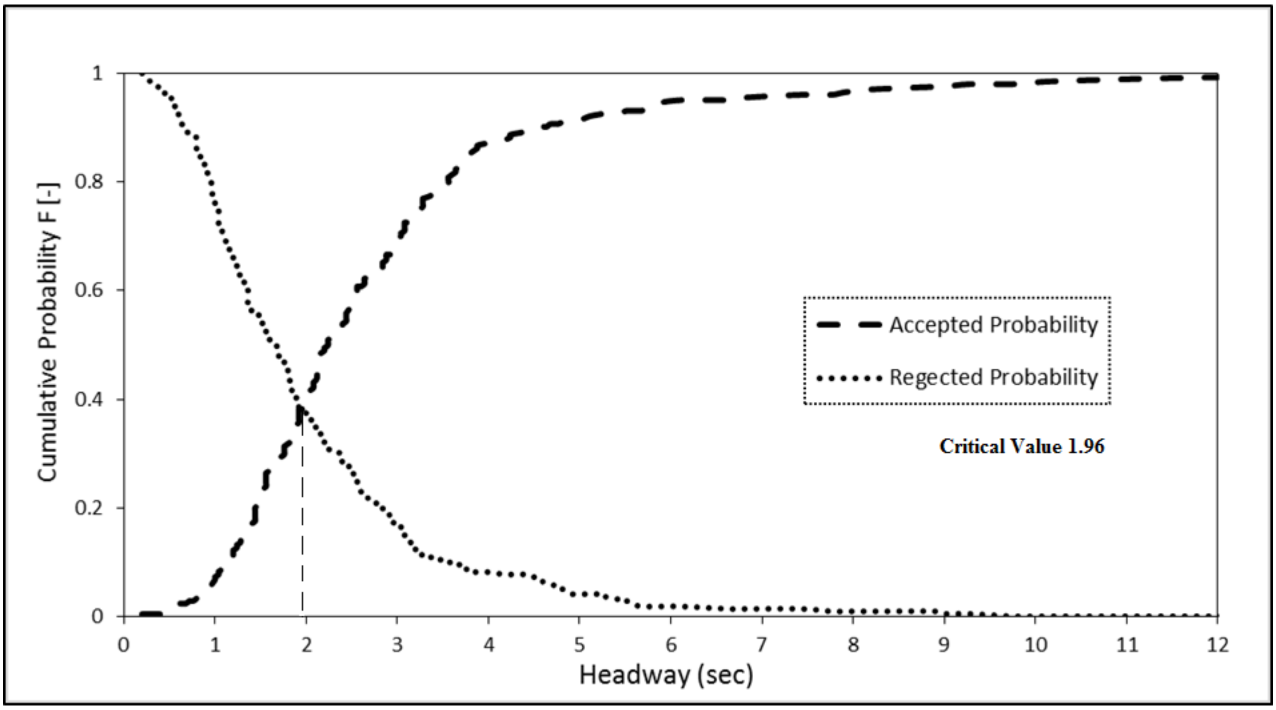


Fig 5.2. Plot of CDF's to determine Critical gap using Raff Method

5.3.2 Critical Gap using Equilibrium of Probabilities Method

This method overcomes certain lacunas of age old methods, like it doesn't take into consideration homogeneous nature of driver behaviour, neither has it required predefined distribution and it is not necessary for an accepted gap to be always greater than the rejected gap. This method thus have very strong base and produces robust results.

For this initially, the probability of occurrence of any headway was calculated using the data extracted. Then, the accumulated frequencies of this probabilities was estimated. The probability distribution functions based on these accumulated frequencies were then computed for accepted, rejected and the critical gap. The mean value of estimated critical gaps gives the value of critical gap using this method.

The table showing the sample of values used to compute critical gap using this method for Chacka junction is shown in Table 5.4 and the plot obtained by this process is shown in Fig 5.3.

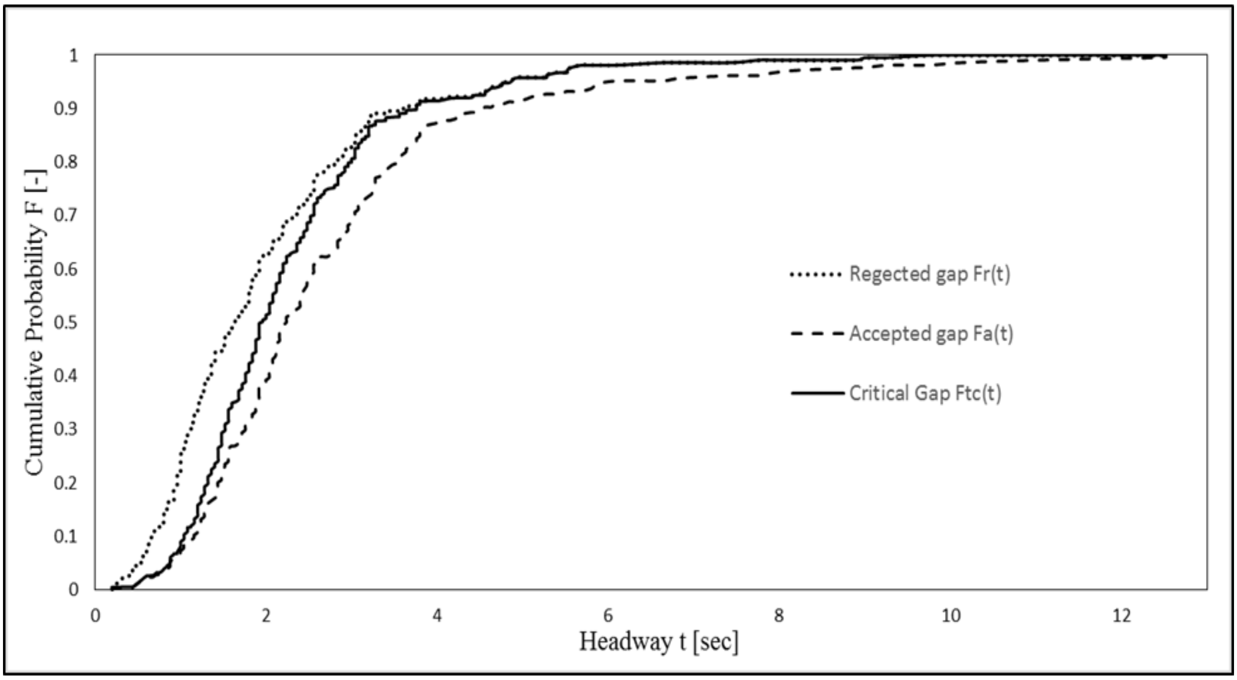


Fig 5.3: Plot of CDF's to determine Critical gap using Equilibrium of probabilities method

5.3.3 Critical gap using Maximum Likelihood Method

After the extraction of data, the headways are arranged in order and then the probability density and accumulative probability were calculated using the NORMDIST function in Microsoft Office Excel 2013.

Table 5.3: Iterations used for estimating be μ and σ

μ	σ	a	b
0.811	0.632	-0.55759	-0.3871
0.81	0.5	-0.69049	-0.3047
0.65	0.35	-0.42115	-0.25846
0.6543	0.3496	-0.43185	-0.256
0.645	0.325	-0.44201	-0.22587
0.655	0.3254	-0.46474	-0.22221
0.5	0.3	-0.0966	-0.2598
0.48	0.35	-0.09811	-0.00442

Table 5.4. Brief details of computing critical gap using equilibrium of probabilities method

1	2	3	4	5	6	7	8	9	10	11	12
Time Interval (sec)*10	A/R	IF '2'=R, nr=n+1	IF '2'=A, na=n+1	Rejected gap, Fr(t)	Accepted gap, Fa(t)	Critical Gap, Ftc(t)	Pc=Ftc(t)-Ftc(T-1)	Td,j=(Tj+Tj-1)/2	Tc,mean=Pc*Td,j	Pc*Td,j^2	(Pc*Td,j)^2
0.208333	R	10	2	0.045249	0.009804	0.010164191	4.74593E-05	0.48	2.27804E-05	1.09346E-05	5.18949E-10
0.192308	A	10	3	0.045249	0.014706	0.015169195	0.005005004	0.5	0.002502502	0.001251251	6.26252E-06
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
0.078125	R	84	30	0.38009	0.147059	0.191740413	0.001124577	1.28	0.001439459	0.001842507	2.07204E-06
0.078125	R	85	30	0.384615	0.147059	0.192878338	0.001137925	1.28	0.001456544	0.001864377	2.12152E-06
0.069444	A	98	41	0.443439	0.20098	0.265306122	0.00478508	1.44	0.006890516	0.009922343	4.74792E-05
0.067568	A	98	42	0.443439	0.205882	0.270029674	0.004723551	1.46	0.006896385	0.010068722	4.75601E-05
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
0.060976	R	111	55	0.502262	0.269608	0.351351351	0.002059705	1.62	0.003336722	0.00540549	1.11337E-05
0.059524	A	111	56	0.502262	0.27451	0.35546875	0.004117399	1.66	0.006834882	0.011345904	4.67156E-05
0.044643	R	153	104	0.692308	0.509804	0.623616236	0.00343275	2.24	0.00768936	0.017224166	5.91263E-05
0.04386	A	153	105	0.692308	0.514706	0.625859697	0.002243461	2.26	0.005070222	0.011458703	2.57072E-05
0.007987	A	221	203	1	0.995098	1	0	11.84	0	0	0
0.007987	A	221	204	1	1	1	0	12.52	0	0	0
							1.000000117		2.271323866		0.026145517

Table 5.5: Brief description of procedure adopted for estimating critical gap using maximum likelihood method

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
i	R	A	Ln (R)	Ln (A)	μ	σ	f_a	F_a	f_r	F_r	R-U	A-U	(12)*(10)	(13)*(8)
1	9.6	12.96	2.261763	2.561868	0.811	0.632	0.013602	0.9972	0.045286	0.989148	1.450763	1.750868	0.065699	0.023816
2	1.04	5.36	0.039221	1.678964	0.811	0.632	0.245826	0.91518	0.299482	0.111011	-0.77178	0.867964	-0.23113	0.213368
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
21	1.04	2.08	0.039221	0.732368	0.811	0.632	0.626371	0.450492	0.299482	0.111011	-0.77178	-0.07863	-0.23113	-0.04925
22	2.04	4.72	0.71295	1.551809	0.811	0.632	0.317569	0.879435	0.623687	0.438354	-0.09805	0.740809	-0.06115	0.235258
25	0.36	3.48	-1.02165	1.247032	0.811	0.632	0.497544	0.754879	0.009425	0.001867	-1.83265	0.436032	-0.01727	0.216945
26	1.72	3.6	0.542324	1.280934	0.811	0.632	0.478778	0.771431	0.576698	0.335375	-0.26868	0.469934	-0.15494	0.224994
27	1.04	3.64	0.039221	1.291984	0.811	0.632	0.472522	0.776686	0.299482	0.111011	-0.77178	0.480984	-0.23113	0.227275
28	0.52	4.68	-0.65393	1.543298	0.811	0.632	0.322593	0.876711	0.043004	0.010227	-1.46493	0.732298	-0.063	0.236234
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
148	0	1.72	0	0.542324	0.811	0.632	0.576698	0.335375	0.277091	0.099706	-0.811	-0.26868	-0.22472	-0.15494
390	0	6.24	0	1.83098	0.811	0.632	0.171633	0.946725	0.277091	0.099706	-0.811	1.01998	-0.22472	0.175062
406	0	11.96	0	2.481568	0.811	0.632	0.019186	0.995895	0.277091	0.099706	-0.811	1.670568	-0.22472	0.032051
				330.2876			186.772	205.1235	113.545	46.10339			-87.2077	2.342451

The critical gap values for different sites undertaken for model development were obtained using these three methods. Significant variation was found in the values estimated by different methods.

5.4. Model Development

After conducting regression analysis for different entries of roundabouts, the relationship between entry and the circulating flow for one minute flow data was observed to be exponential in nature. The equation obtained for the relationship between the entry and the circulating flow can b generalized as given below

$$q_e = A\, e^{-B\, q_c} \qquad 5.1$$

Where, q_e and q_c represent entry and circulating flow in PCU/hr. and A and B are regression co-efficient.

Regarding the headway distribution, M1 distribution was adopted for modelling the capacity. Thus, considering these two relationships, final equation was developed by conducting multiple regression using R package. The equation obtained gave correlation coefficient value of 0.78, proving the efficiency of the model. The critical gap and follow-up were also proved to be significantly affecting the capacity. The final equation thus obtained.

Where, q_e is entry capacity in PCU/h

q_c is circulating flow in PCU/h

t_c is critical gap in sec and

t_f is follow- up time in sec.

5.5 Validation of Model

The above equation which uses the critical gap, follow-up time and circulating flow to determine the value of the entry capacity flow was developed from the extensive data sets obtained from videos of the five roundabouts. To validate this equation which follows the gap acceptance theory we have to check whether it can explain the traffic scenario in other roundabouts. The best way to check this is by plotting the entry capacity value obtained for each circulating flow using this equation over the scatter plot which shows the site traffic condition. If the equation plot stays in the middle of the scatter plot we can say it's a win-win situation. If the plot either goes much higher or much lower we can say that it fails by over-estimating or underestimating at the particular site. To conduct the validation data from five sites Medical Square at Nagpur, Albert Ekka chowk at Ranchi, Valiyakavala at Vaikom, Bisra Chowk at Rourkela and Jobra Chowk at Cuttack was used.

Three critical gap values for an entry has been obtained using three different methods, the validity of this combo i.e. the developed equation with each critical gap value can also be checked under this circumstance. From different studies conducted on the critical gap, it has been concluded that the Ning Wu method (Equilibrium of Probabilities) provided better values. The result obtained after plotting the entry capacity over the scatterplot has been shown in detail below.

5.6 Comparison of Models

Comparing the developed model with different existing ones will give a general idea of how the output varies. Existing models like HCM 2010 and German were used to do this comparison. HCM model uses only critical gap and follow-up time whereas German model considers the minimum circulating headway too. The output obtained is plotted along with the scatterplot of entry and circulating flow obtained from Bisra Chowk, Rourkela. The result obtained is shown in Fig 5.5.

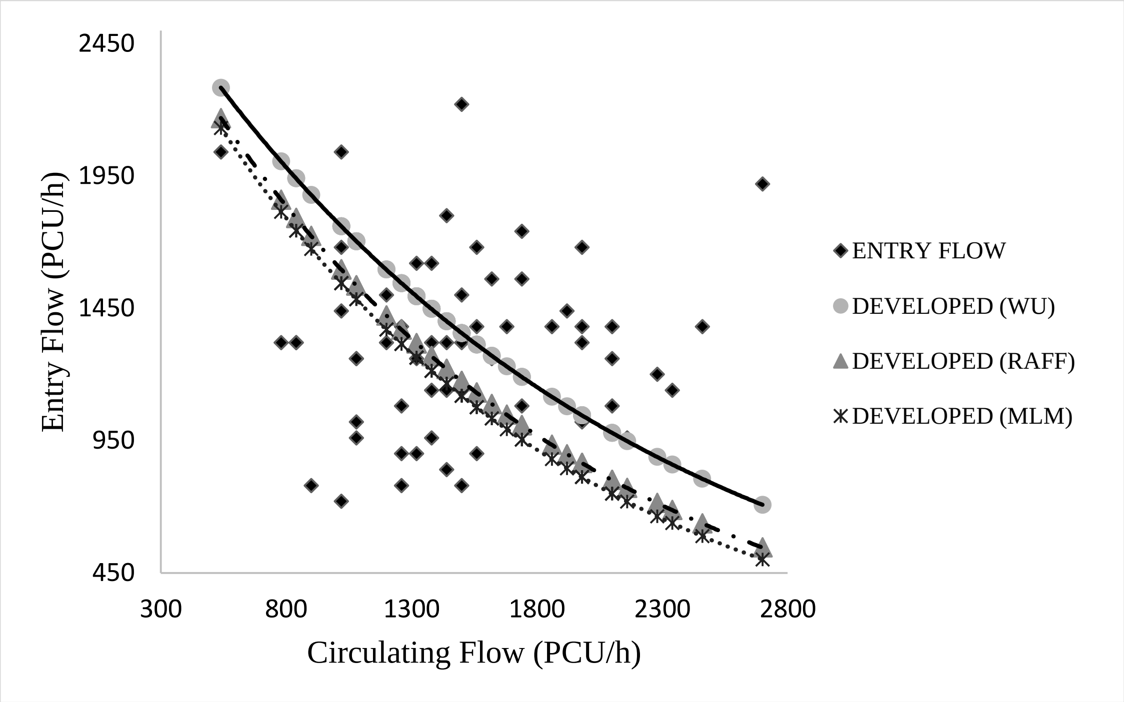


Fig 5.4. Validating using data from Medical Square, Nagpur

6. SUMMARY AND CONCLUSION

6.1. Summary of the study

Driver behaviour, heterogeneity and Indian traffic were the key area which was supposed to be covered by this study. From the study of different literatures and the experience gained from different sites in India one can clearly state that the composition of traffic in India is so heterogeneous and tangled that no comparison can be made with those of the developed nation. A general outlook on this subject can be obtained from Fig 6.1 where the composition of traffic at different roundabouts located at four different states of India are shown.

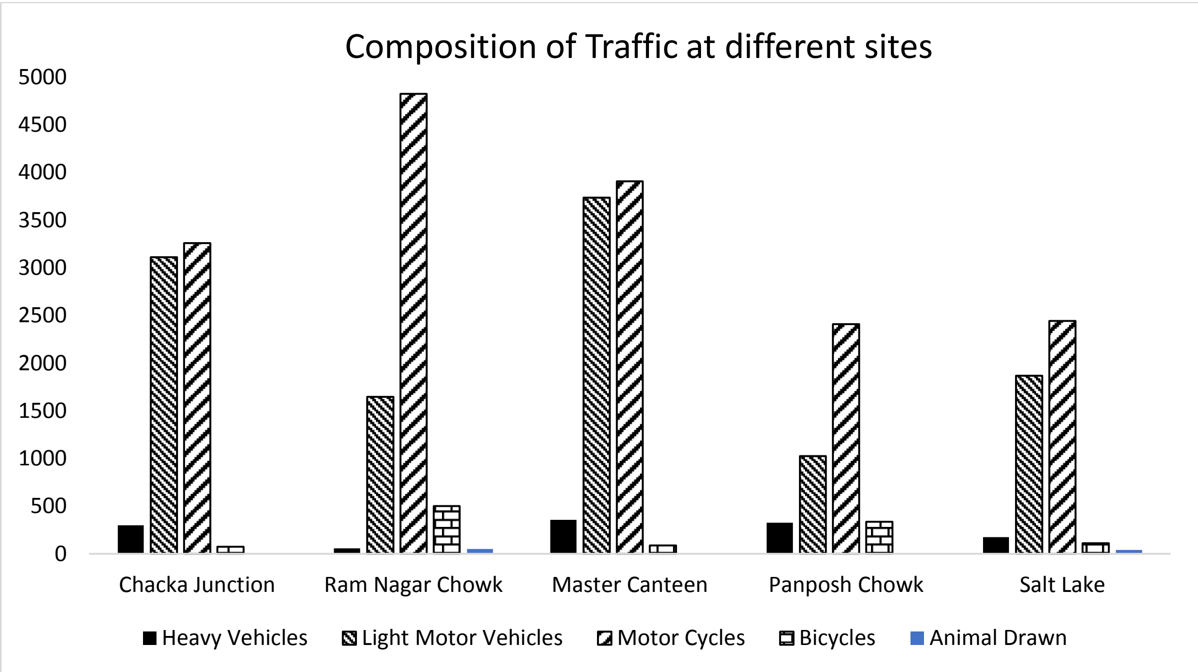


Fig 6.1. Composition of traffic at each site

The one uniformity which can be observed, is the excessive use of two wheelers than other vehicles by people in all these regions. The amount of rickshaws (which are included in the light motor vehicles section) are also considerably high on these roads. Roundabouts located inside the city or where main roads like the national highways meets observes good amount of LMV traffic like in Chacka and Master Canteen. Good percent of heavy vehicles which includes large buses and trucks are also seen in all sites except the residential ones like the Ram Nagar square.

Raff, Maximum likelihood and Equilibrium of probability are the three methods which were used to determine the critical gap value. A standard deviation of about 7 to 23% is observed between the values obtained by these methods for the different sites. From the study of traffic in U.S roads, NCHRP gave standard values for critical gap ranging from 4.1 to 4.6 and for follow-up time ranging from 2.6 to 3.1. While for Indian traffic, the value obtained for critical gap ranged between 2.35 - 0.9 sec and follow-up time ranged between 0.72 – 1.59 sec. Though the studies are conducted in entirely different environment, a comparative analysis can be conducted. This fall in the values may be mainly due to the large concentration of the motorbikes and rickshaws, which creep into every nook and corner humanly possible. The aggressiveness of Indian drivers is also clearly shown by this value.

6.2 Conclusions

A study concerning capacity and performance of roundabouts in India was conducted to check the efficiency of roundabout in terms of capacity. The capacity was taken as an outcome for drivers' behaviour and flow conditions at the site. From the work done so far, the following facts could be concluded:

i. From the detail study, it was observed that the driver behaviour varied from site to site with the change in traffic composition, like the headways were larger when the number of heavy vehicles were more. The critical headways thus, were found to be affected by the number of vehicles entering a roundabout from an approach leg.

ii. Critical gap was computed using three methods namely, Raff, Wu and Maximum likelihood method. For the sites considered the values of critical gap obtained from these three methods changed with a standard deviation of 10-23%.

iii. Regarding the traffic flow, the entry flow of roundabouts was found to vary exponentially with the circulating flow when plotted using one minute interval data.

iv. When validating the model, the critical gap obtained using the equilibrium of probabilities (Wu) method gave a good fit for the data in most of the cases, as it neither underestimated nor overestimated the capacity. This proved the method to be the most suitable for Indian conditions.

v. The developed model provided good fit for moderate valued circulating flow, while overestimated in case of lower circulating flows. This might be due to consideration of only saturated flows in developing the model.

vi. The variations in the results might be due to the fact that only a few sites were used for developing a model. To modify the developed model and form more robust model, more data is to be used.

vii. The comparative study with two existing models, HCM 2010 and German, showed that in maximum cases the HCM 2010 model underestimated the capacity, whereas the German model overestimated when compared to valued obtained by developed model.

6.3. Future Scope

At the end of the present study, it can be finally concluded that the critical gap values using three methods were estimated and compared. An equation using M1 distribution of headways under the gap acceptance theory was developed for determining the entry capacity of roundabout. For further analysis, a statistical study can be conducted to develop a new methodology to determine critical gap for heterogeneity in India as the existing models neglected in this issue. For the purpose of developing the model, a very basic distribution of headways, i.e. M1 distribution was utilized. With further research and more data set, essential data could be extracted and used to develop much precise model using M2, M3 or M4 distribution of headways. This would henceforth consider the effect of minimum circulating headway and the proportion of bunched vehicles in the stream.

Regarding the capacity equation, only the driver behaviour parameters have been accounted for forming it. It can be concluded from various researches that even the geometrics play an important role in determining the capacity. Hence, a model with combination of both geometrics and the gap acceptance theory could be developed for more precise results.

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